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EFFECTS OF DIFFERENCES IN INTERREINFORCER INTERVALS BETWEEN PAST AND CURRENT SCHEDULES ON FIXED-INTERVAL RESPONDING

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Undergraduates were exposed to a mixed fixed-ratio differential-reinforcement-of-low-rate schedule. Values of the schedule components were adjusted so that interreinforcer intervals in one component were longer than those in another component. Following this, a mixed fixed-interval 5-s fixed-interval 20-s schedule (Experiment 1) or six fixed-interval schedules in which the values ranged from 5 to 40 s (Experiment 2) were in effect. In both experiments, response rates under the fixed-interval schedules were higher when the interreinforcer intervals approximated those produced under the fixed-ratio schedule, whereas the rates were lower when the interreinforcer intervals approximated those produced under the different-reinforcement-of-low-rate schedule. The present results demonstrate that the effects of behavioral history were under control of the interreinforcer intervals as discriminative stimuli.

Key words: behavioral history, interreinforcer intervals, mixed schedules, tandem schedules, fixed-interval schedules, screen touch, humans

An organism's current behavior is determined by both its immediate environment and its environmental history (Skinner, 1953). Although the focus of the experimental analysis of behavior has been primarily on the former, some investigators recently have paid attention to the latter, showing formidable effects of historical contingencies on the current behavior with pigeons (e.g., Nader & Thompson, 1987), rats (e.g., Urbain, Poling, Millam, & Thompson, 1978), and monkeys (e.g., Barrett, 1977).

Systematic effects of behavioral history also have been obtained with human subjects. Weiner (1964, 1969) found that humans with histories of fixed-ratio (FR) schedules of reinforcement responded high rate under subsequent fixed-interval (FI) schedules, whereas those with histories of differential-reinforcement-of-low-rate (DRL) schedules responded low rate under the same FI schedules. Major behavioral differences across human subjects (i.e., individual differences) and between humans and nonhumans (i.e., interspecies differences) found in laboratory research may be due to the extensive histories that human subjects have outside the laboratory (Wanchisen, Tatham, & Mooney, 1989). Investigations of history effects, therefore, are considered to be essential for understanding the behavior of organisms, especially human behavior.

Effects of behavioral histories may depend on at least three variables. The first variable, as shown in Weiner (1964, 1969), is the conditions in effect as the history is built (Nader & Thompson, 1989; Urbain et al., 1978). The second is the conditions in effect when the effects of that history are tested. For example, high or low rate responding persists for some time under FI schedules, but it is less persistent under variable-interval (VI) schedules (Freeman & Lattal, 1992; Poling, Krafft, & Chapman, 1980).

The third variable possibly affects the history effects, and the focus of the present study is that of interactions between history-building and testing conditions. For the pigeons of Nader and Thompson (1987), pecking a white center key was reinforced under a VI schedule after pecking a green right key was reinforced under an FR or DRL schedule. Nader and Thompson obtained only transient effects of the previous FR or DRL history, leading them to speculate that their weak effects may have resulted from the change in response key location and color when the VI schedule was introduced. Freeman and Lattal (1992) demonstrated that effects of past schedules on current responding were predominant under the stimuli identical to those presented with the past schedules.

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They exposed pigeons to FR and DRL schedules under different stimulus conditions. Following this, an identical FI or VI schedule was arranged in the presence of both stimulus conditions. Response rates under the FI or VI schedule remained higher in the presence of the stimuli that had previously been correlated with the FR schedule than in the presence of the stimuli that had previously been correlated with the DRL schedule.

Freeman and Lattal (1992) suggested that their effects of behavioral history were under stimulus control. Certainly, the interactions cited above may be better understood in terms of stimulus control and generalization. Stimulus generalization, which mirrors the absence of stimulus control, generally is a function of physical similarity between the training and testing stimuli (Dinsmoor, 1995). Coincident with this aspect of stimulus generalization, the findings of Nader and Thompson (1987) and Freeman and Lattal suggest that when the environmental stimuli experienced during the training and testing conditions are similar, behavioral history has more prolonged effects.

Not only antecedent stimuli such as color or location of operanda, but also consequential stimuli have discriminative properties (Lattal, 1975). Thus, it is likely that changes in some features of reinforcement schedules from past to current conditions also contribute to behavioral history effects. Because at least two different schedules, one for building a history and another for testing the effects of the history, are prerequisite for the assessment of behavioral history effects (Tatham & Wanchisen, 1998), changes in reinforcement rate or interreinforcer interval (IRI), often accompanied with the schedule change, merit careful consideration.

Previous studies outside the area of behavioral history have suggested discriminative properties of IRIs. Discriminative properties of schedules of reinforcement have been investigated using the schedules as sample stimuli in a matching-to-sample procedure (e.g., Lattal, 1975; Rilling & McDiarmid, 1965). Using a similar procedure, Commons (1979) suggested that reinforcement rates functioned as discriminative stimuli. Although it has not been pointed out explicitly, performance in certain mixed schedules may be under the discriminative control of the IRIs. Under a two-component mixed schedule, response rates or patterns generated by a schedule component with shorter IRIs tend to occur immediately after reinforcement. For example, under a mixed FI 330-s FI 30-s schedule, Ferster and Skinner (1957) showed that a run of responses occurred at around 30 s since the previous reinforcement even when the FI 330 s was in effect. The pattern changed thereafter to a sustained lower but slightly accelerating rate. The stimulus that is the best predictor of reinforcement is said to exert the strongest control over responding (Mazur, 1994). Under mixed schedules, there are no stimuli other than the schedules to distinguish the schedule component in effect. Thus, it is plausible that the IRIs of the schedule with the smaller value, such as those of the FI 30 s studied by Ferster and Skinner, can exert discriminative control over the responding.

Some studies of behavioral history effects have attempted to equate the IRIs under the past and current schedules. Freeman and Lattal (1992) and LeFrancois and Metzger (1993) determined values of FI schedules based on the average IRI of the previous training schedules. This generally accepted practice presumably is based on an implicit assumption that the changes in IRIs can be a controlling variable of history effects. With the exception of Tatham, Wanchisen, and Yasenchack (1993), however, there is no published work that examines the influences of differences in IRIs on behavioral history effects. Tatham et al. first exposed three groups of rats to DRL 10-s, 30-s, or 60-s schedules, followed by exposure to an FI 30-s schedule. Rats exposed to the DRL 60-s schedule showed the most persistent low-rate responding under the FI schedule. This result was not consistent with Tatham et al.'s expectation or the present generalization view of history effects. That is, it would be rats exposed to the DRL 30-s schedule who would show the most persistent DRL-like responding because the change in IRIs from the past to the current contingencies should have been the smallest.

At least two procedural features, however, may restrict the generality of Tatham et al.'s (1993) results. First, although the schedule value was different across conditions, all subjects were exposed to a DRL schedule in the training. Because generally low rates of responding occur under DRL schedules, this procedure seems to be sound for isolating effects of changes in IRIs from response rates, although the obtained response rates in the final training sessions were different across schedules. In any case, compared with radically different response rates usually produced by FR and DRL schedules, for example, the differences across the DRL schedules may not have been sufficiently large. By contrast, if the differences in rates of baseline responding were extremely large, the effects of different IRIs may have been observed on responding under the subsequent testing schedule. Second, each subject was exposed to only a single DRL schedule in the training. As a general rule, generalization gradients are flatter—indicating weakness of stimulus control—after responses are reinforced under single stimulus than after the responses are differentially reinforced between two different stimuli (e.g., Hanson, 1959). Even though IRIs could have discriminative properties, they may at best have acquired weak control with the single schedule.

The present study examined effects of differences in IRIs between past and current schedules on the current responding of adult humans using training schedules that produced differential rates of responding. Each subject was exposed first to both FR and DRL schedules to produce large differences in response rates between the two history-building schedules. For building different IRIs, the values of the FR and DRL schedules were adjusted so that the IRIs in the FR schedule were longer than in the DRL schedule for half of subjects and shorter in the FR schedule than in the DRL for the other subjects. Following this training, FI schedules with different values were in effect. No differential stimuli were correlated with any schedules, controlling for the possibility that stimulus variables other than differences in IRIs between conditions could influence the results. Overall response rates usually decrease with increasing FI value in pigeons and rats (Lowe, Harzem, & Spencer, 1979; Skinner, 1938), or are not affected by the value in humans without instructions about response rates or contingencies (Baron, Kaufman, & Stauber, 1969). Regardless of the FI value, however, if the rates were a function of differences in IRIs between training and testing schedules, the IRIs would have acquired discriminative functions and the changes in the IRIs would have affected the behavioral history effects.

EXPERIMENT 1

The basic procedure of Experiment 1 was adapted from experiments investigating stimulus control of behavioral history effects (Freeman & Lattal, 1992). As described above, in Freeman and Lattal antecedent stimuli identical to those presented during the training schedules functioned as discriminative stimuli during the history testing portion of the experiment. Experiment 1, by contrast, examined whether IRIs identical to those of the previous training schedules would function as discriminative stimuli controlling history effects.

METHOD

Subjects

Five male and three female undergraduate students (ages 20 to 22 years) were recruited from an introductory psychology course at Osaka Kyoiku University and served as subjects. This course did not cover behavior analysis, and none of the subjects had any knowledge or experience of operant conditioning experiments.

Apparatus

The experimental room was 1.70 m wide, 2.20 m deep, and 2.17 m high. A Nihon Electric Company PC-9821AP microcomputer, located in an adjacent room, was used to control the experiment. The subject sat facing a color display monitor (250 mm wide by 180 mm high) equipped with a Micro Touch Systems® touch screen on a desk. A white circle 55 mm in diameter was presented in the center of the display monitor, and each touch on the circle (operandum) was defined as a response. All interevent times were recorded with 50-ms resolution in real time. A white circle 30 mm in diameter was presented in the bottom left of the monitor, and each touch on that circle (defined as a consummatory response) produced 100 points. Each touch to the circles was accompanied by a sound through a speaker beneath the desk. Points accumulated during the session were presented on the top right of the monitor.

Procedure

Subjects were required to sign an informed consent agreement that specified the frequency and duration of their participation in the experiment and the average earnings for such participation. At the beginning and at the end of the experiment, each subject was asked not to speak to anyone other than the experimenter about the study in an attempt to prevent discussion about the contingencies among subjects (cf. Horne & Lowe, 1993). At the end of the experiment, each subject was asked whether he or she had any other information to offer about the study. All reported that they did not.

A 90-min experimental period was conducted once per day, two times per week. During this 90-min period, a maximum of five sessions occurred. Sessions were separated by 2- to 3-min breaks during which the experimenter recorded the data and changed the schedules or schedule values if that was called for by the research plan. Upon completion of the experiment, subjects were paid for participation (100 yen per 90 min, approximately 0.93 U.S. dollars) and performance (2 yen per 100 points) and were debriefed.

On the first day of the experiment, after being escorted into the room, each subject was asked to read the instructions. The instructions were written in Japanese and their English translation follows:

> Your task is to earn points. A hundred points are worth two yen. In addition, you will be paid 100 yen for every day you spend in the experiment. Total payment will be made at the end of the experiment.
>
> A circle will be shown in the center of the display monitor. If you touch the circle, the center circle may disappear, then a small circle will appear on the bottom of the display monitor. By touching the small circle, you can earn points. Accumulated points will be shown in the top right of the display monitor.
>
> The words READY and GO will appear in sequence on the display monitor. When the word GO disappears, the task will start. The task will continue until the words GAME OVER appear on the display monitor.
>
> During the task, the word WAIT may appear on the display monitor. When this word appears, please wait until the center circle reappears.

The typed set of instructions remained on the desk throughout the experiment. Questions regarding the experimental procedure were answered by telling the subject to reread the appropriate sections of the instructions. Then the words READY and GO were presented in sequence in the top left of the display monitor. After the word GO disappeared, a circle, which served as the operandum, was presented in the center of the display monitor.

When the schedule requirement was met, the center circle was darkened and the circle for the consummatory response was presented on the bottom left of the monitor. A touch during a 3-s consummatory response period darkened the circle and accumulated 100 points on the top right counter. If the subject did not touch the circle during the consummatory response period, no point accumulation followed. This occurred only four times during the experiment out of 8,960 opportunities for the consummatory response.

A two-component mixed schedule was used. Each component was presented once per session and lasted until 20 reinforcers occurred. The interval between components was 1 min, during which the word WAIT was presented at the top left of the monitor. After the second component ended, the words GAME OVER appeared at the top left of the monitor.

Each of four subjects was randomly assigned to one of two conditions: (a) short FR/long DRL history, or (b) long FR/short DRL history. Short FR/long DRL history subjects were exposed first to a mixed schedule with a low valued FR and a long DRL requirement, whereas long FR/short DRL history subjects were exposed to a mixed schedule with a large FR and a short DRL requirement. Following this, all subjects were exposed to a mixed FI 5-s FI 20-s schedule.

Training Phase

Short FR/long DRL history condition. The training phase lasted 16 sessions for all subjects. A mixed FR 5 DRL 1-s schedule was in effect in the first session of this phase. During the next eight sessions, responding under the FR schedule in the immediately preceding session determined the next FR requirement in order to shorten the IRIs. The FR requirement in each session was set at the number

Table 1

Final value of the FR and the mean interreinforcer interval (ranges in parentheses) in each component of the mixed FR (tandem FT DRL) schedule for each subject in the short FR and long DRL history condition and of the mixed (tandem FT FR) DRL schedule for each subject in the long FR and short DRL history condition in the last five sessions of the training phase of Experiment 1. The mean interreinforcer interval in each component of the mixed FI 5-s FI 20-s schedule in the first five sessions of the testing phase for each subject also is shown.

Subject	FR value	Interreinforcer interval (in seconds)			
		FR[a]	DRL[a]	FI 5-s	FI 20-s
The short FR and long DRL history condition					
1	27	3.7	28.4	5.2	28.0
		(3.4–4.4)	(26.6–30.2)	(5.1–5.3)	(25.0–34.8)
4	21	4.8	25.9	5.6	24.7
		(4.4–5.5)	(25.0–26.9)	(5.1–6.0)	(21.8–26.3)
5	32	4.7	28.6	5.3	21.0
		(3.8–5.9)	(26.9–30.1)	(5.1–5.7)	(20.2–24.0)
7	38	4.2	24.5	5.1	28.7
		(4.0–4.5)	(23.2–25.9)	(5.1–5.1)	(25.6–32.1)
The long FR and short DRL history condition					
2	87	18.5	6.3	6.3	20.1
		(17.3–19.1)	(5.7–6.7)	(6.1–6.6)	(20.1–20.1)
3	104	18.0	6.4	5.6	20.5
		(17.2–18.7)	(5.7–6.9)	(5.2–5.9)	(20.2–21.4)
6	63	18.4	7.8	7.5	22.4
		(15.0–23.2)	(6.7–8.4)	(6.5–8.7)	(21.1–23.8)
8	69	16.8	6.9	7.1	20.1
		(15.7–17.8)	(6.6–7.6)	(6.5–8.1)	(20.1–20.2)

[a] The labels FR and DRL describe the schedule components including FR schedules (FR or tandem FT FR) and DRL schedules (DRL or tandem FT DRL), respectively.

of responses per 5 s in the FR component of the preceding session. For the last seven sessions in the training phase, the FR values were fixed at the mean number of responses per 5 s during FR components in Sessions 5 through 9. Table 1 shows the final FR value for each subject.

The DRL value was increased progressively over the first five sessions. Specifically, the values for the DRL schedule in the second, third, fourth, and fifth sessions were 2 s, 4 s, 8 s, and 15 s, respectively. For the remainder of the sessions in the training phase, a fixed-time (FT) 5-s schedule was followed by the DRL 15-s. Under this tandem FT 5-s DRL 15-s schedule, a response was reinforced if at least 15 s had elapsed without responses since the onset of the DRL link or since the last response during that link. The order of the two components (FR and tandem FT DRL) was random, with the restrictions that the same order could not occur for more than three consecutive sessions and that each order (FR then tandem FT DRL or tandem FT DRL then FR) occurred three times within every block of six sessions.

As described above, not a simple DRL but a tandem FT DRL schedule was used for the short FR/long DRL history subjects. It was noted in the introduction that under a two-component mixed schedule, response rates or patterns generated by a schedule component with shorter IRIs tend to occur immediately after reinforcement even when another schedule with longer IRIs is in effect, probably because of the absence of stimuli distinguishing the schedule component in effect. In the present experiment, discriminative stimuli did not distinguish the schedule component in effect—at least not until the first reinforcement in the first component in every session. Thus, during some of the first intervals in components for the short FR/long DRL history subjects, the FR-like short run was expected to occur in the beginning of intervals even when the FR schedule was not in effect. Such responding would postpone reinforcement if the schedule in effect was a simple DRL. By contrast, because an identical schedule continued until 20 reinforcers occurred, the preceding contingencies of reinforcement may function as discriminative stimuli for the subsequent responding in later intervals in components, leading to the DRL-like low-rate with no short runs. If the schedule in effect was a simple DRL, such responding would not postpone reinforcement, thus producing IRIs shorter than the first ones within the same components. This variability of IRIs within components, however, would be minimized if an FT schedule preceded the DRL. Because the present study was designed to examine the effect of differences in IRIs between past and current schedules, constant-length IRIs with less variability were preferred. Thus, the tandem FT DRL schedule was used instead of a simple DRL. Under the tandem FT DRL schedule, high-rate short runs immediately after reinforcement do not postpone reinforcement when the FT, the first link of the schedule, was in effect. For the same reason, a tandem FT FR schedule replaced a simple FR in the training phase of the long FR/short DRL history condition as described below.

Long FR/short DRL history condition. Training procedures in this condition were identical to those in the short FR/long DRL condition with the following exceptions. During Sessions 2 through 9, the FR requirement in each session was set at the number of responses per 15 s in the FR component of the preceding session. For the remainder of the sessions in the training phase, the FR values were fixed as the mean number of responses per 15 s during FR components in Sessions 5 through 9 (see Table 1). From the sixth session, an FT 5-s schedule was followed by the FR (i.e., a tandem FT FR schedule). The DRL value was increased progressively over the first 4 sessions. The values for the DRL schedule in the second, third, and fourth sessions were 2 s, 3 s, and 5 s, respectively. For the remainder of the sessions in the training phase, the DRL schedule value was fixed at 5 s.

Testing Phase

Following the training phase, all subjects were exposed to a mixed FI 5-s FI 20-s schedule, defining the testing phase for 12 sessions. The procedure in the testing phase was identical to that of the training phase except for the schedule changes.

Results

Training Phase

Table 1 shows the mean IRI in each schedule component for the last five sessions in the training phase and for the first five sessions in the testing phase for each subject. For Subjects 4 and 5 in the short FR/long DRL history condition, the ranges of the IRIs for the FR and FI 5-s components overlapped, whereas the ranges for the FR were shorter than those for the FI 5-s for Subjects 1 and 7. For all subjects except Subject 5, the ranges of the IRIs for the tandem FT DRL and FI 20-s components overlapped, whereas the range for the tandem FT DRL was longer than that for the FI 20-s for Subject 5. In general, the mean IRIs for the FR and the tandem FT DRL components, respectively, were approximately the same as those for the FI 5-s and FI 20-s. For Subject 6, the ranges for the tandem FT FR and FI 20-s components overlapped. For the other subjects, the ranges of the IRIs for the tandem FT FR schedule component were shorter than, but close to, those for the FI 20-s. For all subjects in this condition, the ranges of the IRIs for the DRL and FI 5-s components overlapped. Thus, IRIs for the tandem FT FR and the DRL components, respectively, were not exactly equal to, but were close to, those under the schedules arranged in the testing phase.

Figure 1 shows the response rates of each subject for each session. With continued exposure to the contingencies, response rates in the training phase increased in the components including FR schedules (FR or tandem FT FR), whereas they decreased in the components including DRL schedules (DRL or tandem FT DRL). It should be noted that response rates in the components including FR schedules were extremely high, sometimes as much as 500 responses per minute in some subjects. Informal observation revealed that they often touched the circle with two fingers, the index and middle fingers of one hand. Using these two fingers, they drummed the circle with extremely high rates.

Figure 2 shows cumulative records from the final session of the training phase for a representative subject from each history con-

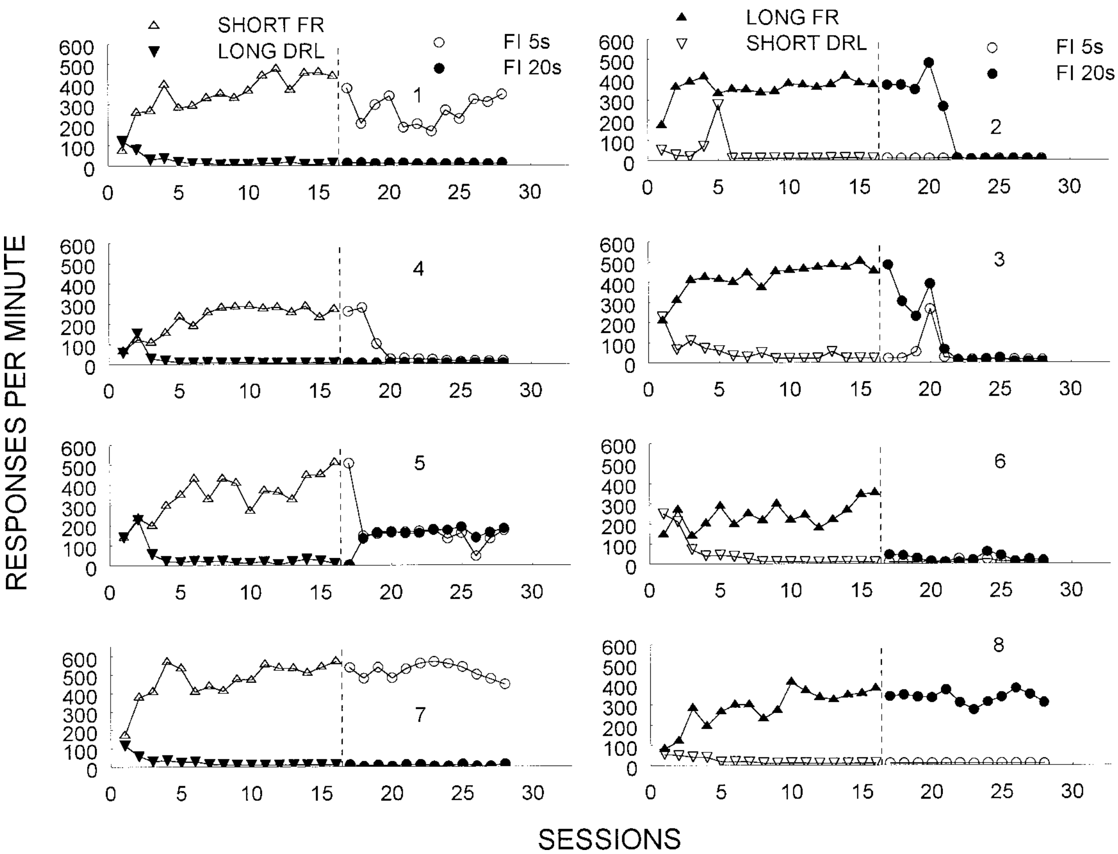

Fig. 1. Response rates in each session for each subject in the short FR and long DRL history condition (left) and the long FR and short DRL history condition (right) of Experiment 1. Open triangles represent responding under an FR schedule that produced short IRIs. Inverted filled triangles represent responding under a tandem FT DRL schedule that produced long IRIs. Open circles represent responding under an FI 5-s schedule. Filled circles represent responding under an FI 20-s schedule. Filled triangles represent responding under a tandem FT FR schedule that produced long IRIs. Inverted open triangles represent responding under a DRL schedule that produced short IRIs.

dition. Consistent with the overall data in Figure 1, these within-session data indicate that response rates for both subjects were higher in the components including the FR than in the components including the DRL. For Subject 1 in the short FR/long DRL history condition, a run was followed by a pause during the first interval of the tandem FT DRL schedule component, whereas a brief pause was followed by a run during the first interval of the tandem FT FR for Subject 8 in the long FR/short DRL history condition. Following the first reinforcement, the response rates were low without a response run in the tandem FT DRL component for Subject 1, whereas the rates were high without pauses in the tandem FT FR component for Subject 8.

Testing Phase

During at least the first two sessions of the mixed FI 5-s FI 20-s schedule, response rates were higher in the FI 5-s schedule component than in the FI 20-s for all subjects in the short FR/long DRL history condition (see Figure 1). For Subjects 1, 4, and 7, the rates in the FI 5-s were higher than in the FI 20-s during all sessions of the testing phase, although the rates for Subject 4 decreased in Sessions 3 and 4 and remained low throughout this phase. For Subject 5, the response rates in the FI 5-s were substantially higher than the FI 20-s during the first session and marginally so during the second. The rates were lower in the FI 5-s component than in the FI 20-s component for the last five ses-

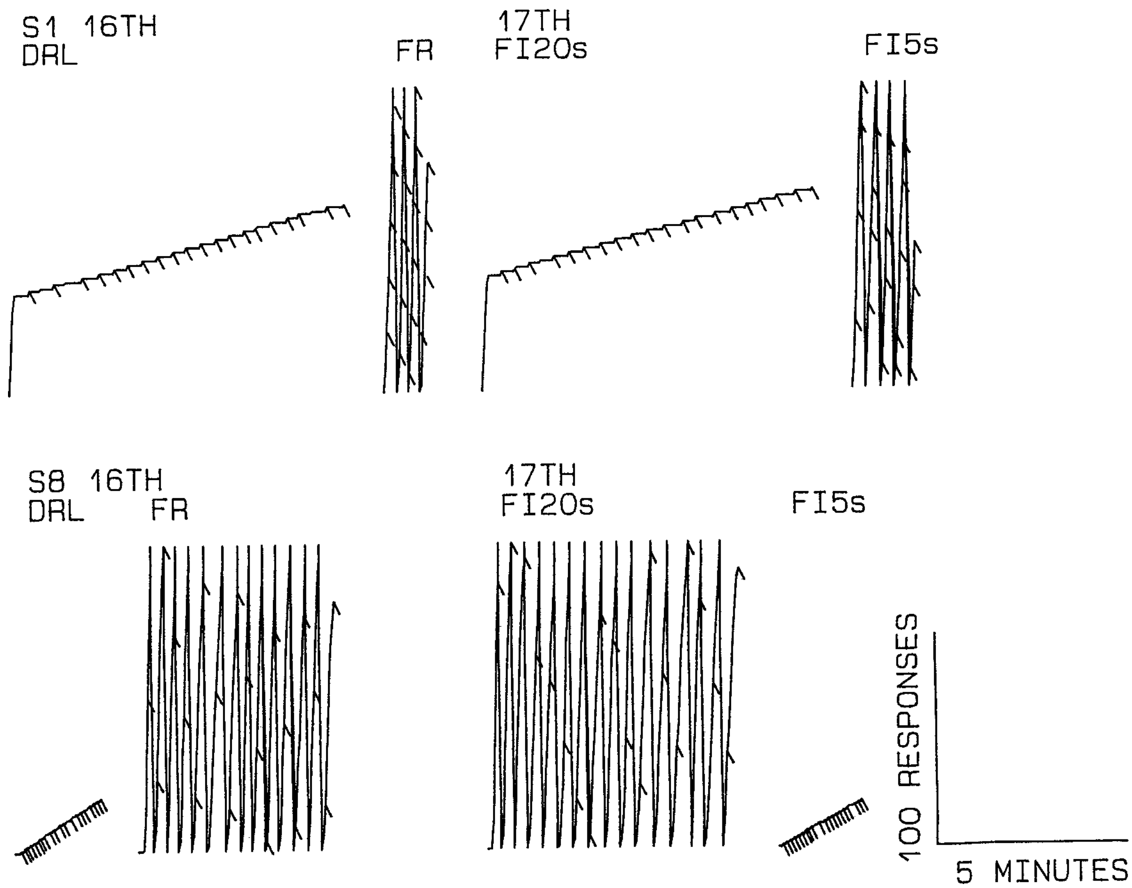

Fig. 2. Cumulative records of responding for Subject 1 in the short FR and long DRL history condition (upper) and Subject 8 in the long FR and short DRL history condition (lower) during the last session of the training phase (left) and the first session of the testing phase (right) of Experiment 1. Order of schedule components shown is the order in which they occurred in a session. The labels FR and DRL identify the components including FR schedules (FR or tandem FT FR) and DRL schedules (DRL or tandem FT DRL), respectively.

sions after the rates in the two components converged.

By contrast, for all subjects in the long FR/short DRL history condition, response rates were initially lower in the FI 5-s schedule component than in the FI 20-s. The rates were lower in the FI 5-s than in the FI 20-s during the first three sessions of the testing phase for Subject 6, the first five sessions for Subjects 2 and 3, and all sessions for Subject 8. For Subject 6, the rates in the FI 5-s component were lower than in the FI 20-s component during the last five of the six sessions, whereas those in the FI 5-s component were higher than in the FI 20-s component during the last six sessions for Subject 2 and six of the last seven sessions for Subject 3.

Figure 2 also shows cumulative records for Subjects 1 and 8 in the first session of the testing phase. For Subject 1, with a history of high-rate responding with short IRIs and low-rate responding with long IRIs, the rates of responding were high under the FI 5-s schedule component and low under the FI 20-s component. For Subject 8, with a history of low-rate responding with short IRIs and high-rate responding with long IRIs, the rates of responding were low under the FI 5-s schedule component and high under the FI 20-s component. Patterns of responding in the first interval of longer schedules of the training schedules carried over to the FI 20-s schedule. That is, during the first interval of the FI 20-s schedule component, run-and-break and break-and-run patterns of responding were observed for Subjects 1 and 8, respectively.

Discussion

Whether effects of past schedules persist indefinitely or are eliminated by current schedules is one of the controversial issues in the study of behavioral history. Some investigators have reported data implying that response rates under current schedules are irrevocably affected by prior exposure to different schedules (Johnson, Bickel, Higgins, & Morris, 1991; LeFrancois & Metzger, 1993; Urbain et al., 1978; Wanchisen et al., 1989; Weiner, 1964, 1969), whereas others have reported only transitory effects of schedule history (Baron & Leinenweber, 1995; Cohen, Pedersen, Kinney, & Myers, 1994; Cole, 2001; Freeman & Lattal, 1992). Regardless of the persistence, however, responding carried over from the training to the subsequent testing schedule generally has been described as a behavioral history effect.

The present results were short-lived but consistent across subjects. That is, responding under FI schedules with short IRIs and long IRIs mirrored those previously engendered under schedules with short and long IRIs. This relation of IRIs and response rates between training and testing conditions, obtained from procedures where schedule contingencies were the only stimuli distinguishing these conditions, suggests that responding under the FI schedules depended on similarities and differences between IRIs produced by the past and current schedules. In Freeman and Lattal (1992), differentiation of response rate between two antecedent stimulus conditions, which had been established by FR and DRL schedules, was maintained under a novel schedule, indicating stimulus control of behavioral history effects. In this context, the history effects in the present experiment may be described as under the control of IRIs as discriminative stimuli. One duration (long or short) of IRIs controlled high rates of responding, whereas another duration (short or long) of IRIs controlled low rates.

The results of Experiment 1 demonstrated a history effect resulting from differences in IRIs when the differences were varied in an all-or-none fashion; that is, IRIs between conditions were either similar or different. The generality of these results was examined in Experiment 2, where the IRI differences were varied in a more continuous fashion.

EXPERIMENT 2

The basic procedure of Experiment 2 was adapted from experiments on stimulus generalization (Harrison, 1991). Fixed-interval schedules with six different values from 5 s to 40 s were presented for testing the effects of FR and DRL schedule histories. Experiment 2 examined whether FI responding would change systematically as a function of differences between IRIs produced by the previous FR and DRL schedules and those produced by the subsequent FI schedules.

Method

Subjects and Apparatus

Three male and five female undergraduate students (ages 18 to 19 years) served as subjects. Details of subject recruitment, informed consent, subject payment, and apparatus were as described in Experiment 1.

Procedure

Training Phase. Each of four subjects was randomly assigned to one of two conditions: (a) short FR/long DRL history, or (b) long FR/short DRL history. The details of the procedure used in the training phase were as described in Experiment 1, except for the last 10 sessions. During the last 10 sessions of the training phase, each component of the mixed schedule of FR and tandem FT DRL or of tandem FT FR and DRL lasted until four reinforcers occurred. The interval between components was 5 s. The order of the two schedules was random, with the restrictions that the same schedule could not occur for more than three consecutive components and that a total of five components occurred in each schedule in every session.

Testing Phase. The testing-phase procedure was identical to that during the last 10 sessions of the training phase with the following exceptions. Each of the following schedules was in effect: FI 5-s, FI 10-s, FI 15-s, FI 20-s, FI 30-s, and FI 40-s. Table 2 shows the sequence of these FI schedules during testing. In each session, two FI test components (probes) were interspersed quasi-randomly

Table 2

Sequence of exposure to different FI schedules in the testing phase of Experiment 2. The labels First and Second, respectively, describe the schedules interspersed earlier and later among baseline components. See text for details.

Session	First	Second
1	FI 5-s	FI 20-s
2	FI 10-s	FI 30-s
3	FI 15-s	FI 40-s
4	FI 20-s	FI 5-s
5	FI 30-s	FI 10-s
6	FI 40-s	FI 15-s
7	FI 40-s	FI 15-s
8	FI 30-s	FI 10-s
9	FI 20-s	FI 5-s
10	FI 15-s	FI 40-s
11	FI 10-s	FI 30-s
12	FI 5-s	FI 20-s

among eight baseline components of the mixed (FR) (tandem FT DRL) schedule for the short FR/long DRL history subjects or the mixed (tandem FT FR) (DRL) schedule for the long FR/short DRL history subjects. Values of the baseline schedules were the same as those during the final sessions in the training phase. Table 3 shows the final FR value. The FI schedule was never presented as the first component of the session and the different FI components did not occur in succession. These probes were employed after pilot data suggested that when the contingencies switched to testing schedules completely, as in Experiment 1, the effects of the previous histories declined rapidly with exposure to FI schedules with a wide range of values.

Results

Training Phase

Table 3 shows the mean response rate and the mean IRI in each schedule component for the last five sessions of the training phase for each subject. For the short FR/long DRL history subjects, the mean IRIs in the FR component were between 3.3 s and 6.3 s. Except for Subject 10, whose mean IRI was 46.2 s, the mean IRIs in the tandem FT DRL component were between 23.5 s and 28.2 s. For the long FR/short DRL history subjects, the mean IRIs in the tandem FT FR schedule

Table 3

Final value of the FR, and the mean response rate and interreinforcer interval (ranges in parentheses) in each component of the mixed FR (tandem FT DRL) schedule for each subject in the short FR and long DRL history condition and of the mixed (tandem FT FR) DRL schedule for each subject in the long FR and short DRL history condition in the last five sessions of the training phase of Experiment 2.

Subject	FR value	Responses per minute		Interreinforcer interval (in seconds)	
		FR[a]	DRL[a]	FR[a]	DRL[a]
The short FR and long DRL history condition					
9	27	259.8	31.0	6.3	27.9
		(218.1–289.4)	(20.3–39.7)	(5.6–7.4)	(22.0–33.3)
10	11	162.3	16.7	4.1	46.2
		(136.1–192.7)	(11.2–21.7)	(3.4–4.9)	(38.5–53.3)
13	14	256.2	11.8	3.3	23.5
		(207.2–281.8)	(9.3–15.0)	(3.0–4.1)	(22.5–24.6)
15	35	356.0	25.0	6.0	28.2
		(288.0–432.7)	(17.6–41.2)	(4.9–7.3)	(25.6–31.5)
The long FR and short DRL history condition					
11	58	280.4	14.5	16.8	8.6
		(263.4–298.9)	(12.7–17.3)	(16.2–17.5)	(7.1–9.7)
12	91	384.2	38.9	18.5	8.0
		(332.1–440.4)	(7.6–91.6)	(16.9–20.3)	(6.7–9.5)
14	51	250.3	11.1	16.3	7.7
		(229.2–271.6)	(7.7–16.7)	(15.3–17.6)	(7.4–8.0)
16	85	362.5	10.3	18.2	6.6
		(327.2–386.3)	(10.0–10.6)	(17.5–19.9)	(6.1–7.2)

[a] The labels FR and DRL describe the schedule components including FR schedules (FR or tandem FT FR) and DRL schedules (DRL or tandem FT DRL), respectively.

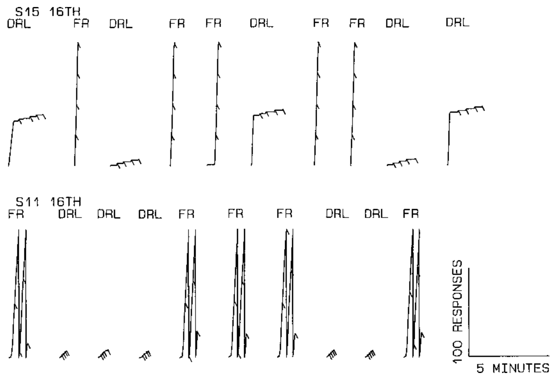

Fig. 3. Cumulative records of responding for Subject 15 in the short FR and long DRL history condition (upper) and Subject 11 in the long FR and short DRL history condition (lower) during the last session of the training phase of Experiment 2. Details are as in Figure 2.

component were between 16.3 s and 18.5 s, whereas the mean IRIs in the DRL schedule component were between 6.6 s and 8.6 s.

For all eight subjects, final response rates in the training phase were higher in the components including FR schedules than in the components including DRL schedules (Table 3). Figure 3 shows cumulative records of the final session of the training phase for a representative subject from each history-training condition. As noted, response rates for both subjects were higher in the components including the FR than in the components including the DRL. For Subject 15 in the short FR/long DRL history condition, a run of responding was followed by a pause during the first intervals of the first, third, and fifth components of the tandem FT DRL schedule. In contrast, a pause was followed by a run of responding during the first interval of the third component of the FR. For Subject 11 in the long FR/short DRL history condition, a brief pause was followed by a run during the first interval of every component of the tandem FT FR schedule. These results replicate the findings in Experiment 1, showing that response patterns generated by the schedule components with shorter IRIs occurred repeatedly in the first interval of the schedule components with longer IRIs.

Testing Phase

Figure 4 shows the mean response rates in all sessions of the testing phase for each subject for each FI value. For all subjects in the short FR/long DRL history condition, response rates under the FI 5-s schedule were higher than under the FI 20-s schedule. In contrast, for all subjects in the long FR/short DRL history condition, response rates under the FI 5-s schedule were lower than under the FI 20-s schedule. These results replicate those of Experiment 1, indicating that the responding under the FI 5-s and FI 20-s schedules depended on schedules to which subjects had been exposed previously.

With the exception of high-rate responding under the FI 30-s schedule for Subject 9, the response rates tended to decrease as a function of the FI value for subjects in the long FR/short DRL history condition (Figure 4). The rates decreased from the FI 5-s through the FI 30-s schedules and increased from the FI 30-s through the FI 40-s schedules for Subjects 10 and 15. The response rates generally tended to increase as a function of the FI value for subjects in the short FR/long DRL history condition. The rates increased from the FI 5-s through the FI 20-s schedules and decreased from the FI 20-s through the FI 40-s schedules for Subject 14. For Subjects 11 and 16, the rates increased from FI 5-s through FI 30-s and decreased from FI 30-s through FI 40-s. These results indicate that the relation between FI values and response rates was affected by the previous histories and probably by differences in IRIs between the past and current schedules.

Figure 5 shows cumulative records for Subjects 15 and 11 in the FI components of the testing phase. Response rates for Subject 15 were high in three of four components of the FI 5-s schedule and two of four components of the FI 10-s schedule. In contrast, the rates were low when the value of the FI schedules was longer than 10 s except for the first component of FI 40-s. Response rates for Subject 11 were low in all components of the FI 5-s schedule and three of four components of the FI 10-s schedule. The rates were medium under the FI 15-s schedule. When the value of the FI schedules was longer than 15 s, the response rates were high. The performances obtained from the other subjects in the short FR/long DRL history condition and the long FR/short DRL history condition differed in no important respects from those shown for Subjects 15 and 11, respectively. These within interval data were consistent with the results

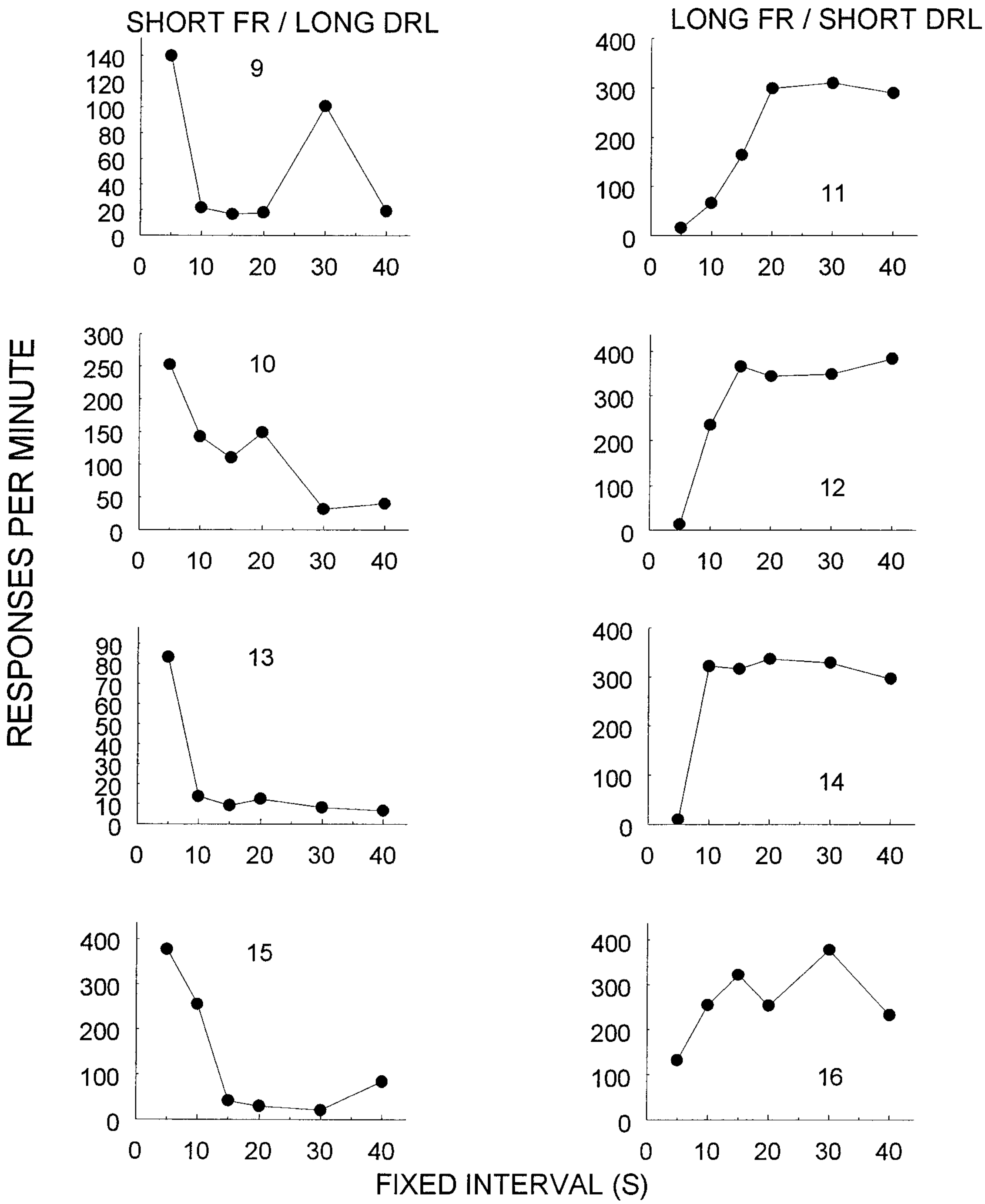

Fig. 4. Mean response rates as a function of FI value for each subject in the short FR and long DRL history condition (left) and the long FR and short DRL history condition (right) of Experiment 2. Data are from all sessions of the testing phase.

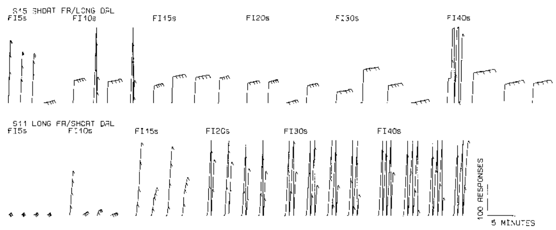

Fig. 5. Cumulative records of responding for Subject 15 in the short FR and long DRL history condition (upper) and Subject 11 in the long FR and short DRL history condition (lower) during the FI components of the testing phase of Experiment 2. From left to right, records of FI 5-s, FI 10-s, FI 15-s, FI 20-s, FI 30-s, and FI 40-s are shown. The order of schedule components shown within each FI value is the order in which they occurred in the 12 sessions of the testing phase.

from overall-session data in Figure 4, suggesting that response rates in each FI value were affected by the differences in IRIs between the past and current schedules.

Similar to Experiment 1, patterns of responding under the schedules with longer IRIs in the training phase carried over to the FI schedules. For Subject 15, a response run was followed by a pause during the first interval of two, four, three, two, and three components under the FI 10-s, FI 15-s, FI 20-s, FI 30-s, and FI 40-s schedules, respectively (Figure 5). During the first IRI of the second FI 30-s component, a pause shifted to a response run, then returned to a pause, whereas a response run shifted to a pause, then returned to a response run during the first interval of the first FI 40-s component. For Subject 11, every component of each FI schedule began with a brief pause.

Discussion

Overall response rates decrease with increasing FI value in pigeons and rats (Lowe et al., 1979; Skinner, 1938), or are not affected by the value in humans (Baron et al., 1969). The results of Experiment 2, however, suggest that such a relation does not necessarily emerge immediately after exposure to different schedules. The relation between the FI value and the response rate for subjects with a history of short FR and long DRL schedules was similar to that generally found in a steady state; that is, decreasing rates with increasing FI value. The relation obtained from subjects with a history of long FR and short DRL was quite different, however, in that the rates increased with increases in the FI value (Subjects 11, 12, 14, and 16 in Figure 4). Even for subjects with the history of short FR and long DRL schedules, the response rates increased slightly when the FI value increased from 30 s to 40 s (Subjects 10 and 15 in Figure 4). These results were correlated with differences in IRIs between the FI schedules and the previous schedules, suggesting that the history effects were generalized across the IRIs as discriminative stimuli.

GENERAL DISCUSSION

In the present experiments, responding established with FR schedules occurred at a high rate under subsequent FI schedules, which is consistent with previous studies (e.g., Nader & Thompson, 1989; Urbain et al., 1978; Weiner, 1964). These results, however, were obtained only when IRIs under the FI schedules approximated those under the FR schedules. Thus, the present results cannot be predicted alone by either the schedules used to build the history or by those schedules used to examine the history effects. Instead, the results are explained by interactions between the history-building and testing conditions. Nader and Thompson (1987) and Freeman and Lattal (1992) noted a similar effect of these interactions, especially with respect to the differences in stimuli correlated with the different history-training and history-testing conditions. The present results also emphasize this role by indicating that the differences in IRIs between the history-building and testing schedules affect responding under the testing schedules.

The present data were generated under limited conditions, however, and the generality of the results across species or schedules warrants discussion. The shorter-term effects observed in the present experiments also raise the question of the replicability of the results. These issues may be related to a discussion of three levels of behavioral history effects: (a) human-nonhuman differences and similarities, (b) discriminative properties of IRIs, and (c) behavioral history effects as transition states.

Human-Nonhuman Differences and Similarities

The generality across species is a principal problem because the present data were from human subjects whose performances under reinforcement schedules have been said to differ from those of nonhuman animals. Such human-nonhuman differences are still a matter of controversy. Some research suggests that human behavior is as sensitive to reinforcement as is nonhuman behavior (e.g., Madden & Perone, 1999; Matthews, Shimoff, Catania, & Sagvolden, 1977), whereas other research suggests that human behavior is much less sensitive (e.g., Baron et al., 1969; Horne & Lowe, 1993). Some investigators have argued that important procedural variations between human and nonhuman research may account for many of the behavioral differences (e.g., Perone, Galizio, & Baron, 1988; Weiner, 1983), and others have suggested that there are fundamental differences in the principles that govern human and nonhuman behavior, with human verbal behavior playing a major role in the former (e.g., Lowe, 1979; Wearden, 1988).

Compared with previous human studies, surprising orderly results were obtained from the present experiments. For example, for all subjects in the present two experiments, response rates were differentiated between the FR and DRL schedules. These performances are consistent with those from nonhumans, but contrast with those from most human studies. Even under a multiple (not mixed) FR DRL schedule, in previous experiments 3 of 4 subjects (Hayes, Brownstein, Zettle, Rosenfarb, & Korn, 1986), 13 of 19 subjects (Hayes, Brownstein, Haas, & Greenway, 1986), 9 of 10 subjects (Rosenfarb, Newland, Brannon, & Howey, 1992), and 3 of 15 subjects (Wulfert, Greenway, Farkas, Hayes, & Dougher, 1994) failed to differentiate response rates between the components when they were not instructed about response rates or contingencies. With respect to procedural differences between the present experiments and the others, the present practice of gradually increasing values of the schedules should be noted. This shaping practice used in the present experiments was not employed in the previous human research cited above, but such practices are common in nonhuman experiments. Using this procedure with humans, Okouchi (1999) also differentiated response rates between FR and DRL components in a multiple schedule. Thus, the present results provide an example of how procedural variations between human and nonhuman research may account for behavioral differences between the two populations.

Discriminative Properties of Interreinforcer Intervals

Tatham et al. (1993) did not find effects of differences in IRIs between training and testing schedules on the testing performances when the training schedule was a single DRL that produced low-rate responding. In contrast, the present experiments found systematic effects when the training schedules were FR and DRL schedules that produced large differentiation of response rates between them. If the inconsistency of the results of Tatham et al. and the present experiments are due to these procedural differences, the present findings may not be replicated in the typical experiments of behavioral history with single training schedules (e.g., Baron & Leinenweber, 1995; Johnson et al., 1991; Nader & Thompson, 1987, 1989; Urbain et al., 1978; Weiner, 1964). Recently, however, parallel exposure to two different training schedules producing large differences in response rates have been demonstrated to be useful for the within-subject examination of history effects (Freeman & Lattal, 1992; Ono & Iwabuchi, 1997). For examining the effects of remote histories, such two different training schedules sometimes have been exposed sequentially; that is, one schedule was followed by another (Cole, 2001; LeFrancois & Metzger, 1993; Weiner, 1969). The present results suggest that in such experiments, differences in IRIs between the training schedules may establish the discriminative function of the IRIs, and thereby affect responding under the subsequent testing schedules.

The present findings also relate to the understanding of the discriminative properties of reinforcement schedules. Reinforcement has been considered as an event that not only maintains responding but also provides a discriminative stimulus for subsequent responding (e.g., Catania & Reynolds, 1968). As described in the introduction, the discriminative properties of reinforcement contingencies and IRIs have been demonstrated in a matching-to-sample procedure in which the schedules were used as sample stimuli (Commons, 1979; Lattal, 1975). The present experiments, following the pioneering work with pigeons by Ferster and Skinner (1957), demonstrated the discriminative properties of IRIs in performance of humans under mixed schedules.

Behavioral History Effects as Transition States

As noted earlier, findings on the persistence of behavioral history effects have been inconsistent (Baron & Leinenweber, 1995; Cohen et al., 1994; Freeman & Lattal, 1992; Johnson et al., 1991; LeFrancois & Metzger, 1993; Urbain et al., 1978; Wanchisen et al., 1989; Weiner, 1969). Cole (2001) speculated this inconsistency might be due to differences in amount of exposure to the testing schedules. He exposed rats first to FR and/or DRL schedules then to an FI schedule and found that the effects of the previous schedules disappeared within 79 to 134 sessions of the FI test. Because stimulus control or generalization is transitory by nature, the present view of history effects is like that of Cole in that history effects are considered as transition states. The focus of the present experiments was not on history effects after extended exposure to testing schedules, but rather on the effects immediately after switching from training schedules. Thus, data for only 12 testing sessions were collected, particularly in Experiment 2, where the data were from probes interspersed among the training schedules. Even with such short-term exposure, however, effects of the previous schedules declined for five of eight subjects in Experiment 1. These results provide additional evidence of history effects as transition states.

The relatively short-lived effects in Experiment 1 also suggest that features of the present procedures may have affected response persistence. The most salient feature was the mixed schedules, which have not been used in previous experiments on behavioral history. Mixed schedules in the present experiments produced complicated and variable patterns of responding (see Figures 2, 3, and 5). Increased variability of responding increases sensitivity to contingency change; that is, decreases persistence of history effects (Joyce & Chase, 1990).

Summary

The present experiments illustrate that behavioral history effects were a function of similarities or differences in IRIs between past and current schedules. The results demonstrate that the IRIs had discriminative properties and suggest that the history effects were under stimulus control of those IRIs. The implications of these results are as follows: (a) Although operant behavior with humans often has been said to be variable across individuals or different from other species, orderly results that are replicable across species may be obtained with human subjects under certain procedures; (b) when subjects are exposed to two different schedules producing large differences in response rates and IRIs, the IRIs can function as discriminative stimuli and thereby affect responding under subsequent schedules; and (c) behavioral history effects may be conceptualized in part as a variation of stimulus generalization, and be characterized as transition states.

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